Aug. 28, 1962 R. D. LYNN 3,051,893

CELL FOR DETERMINING DRILLING MUD RESISTIVITIES

Filed April 22, 1959 2 Sheets-Sheet 1

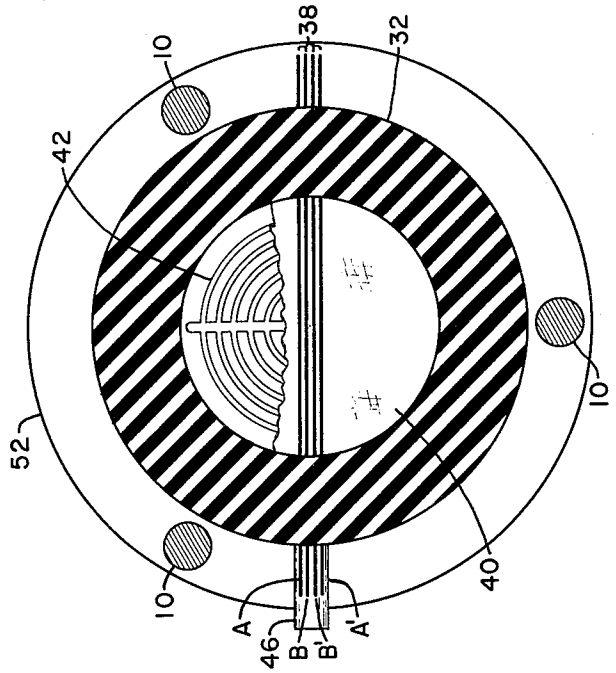


FIG. 2

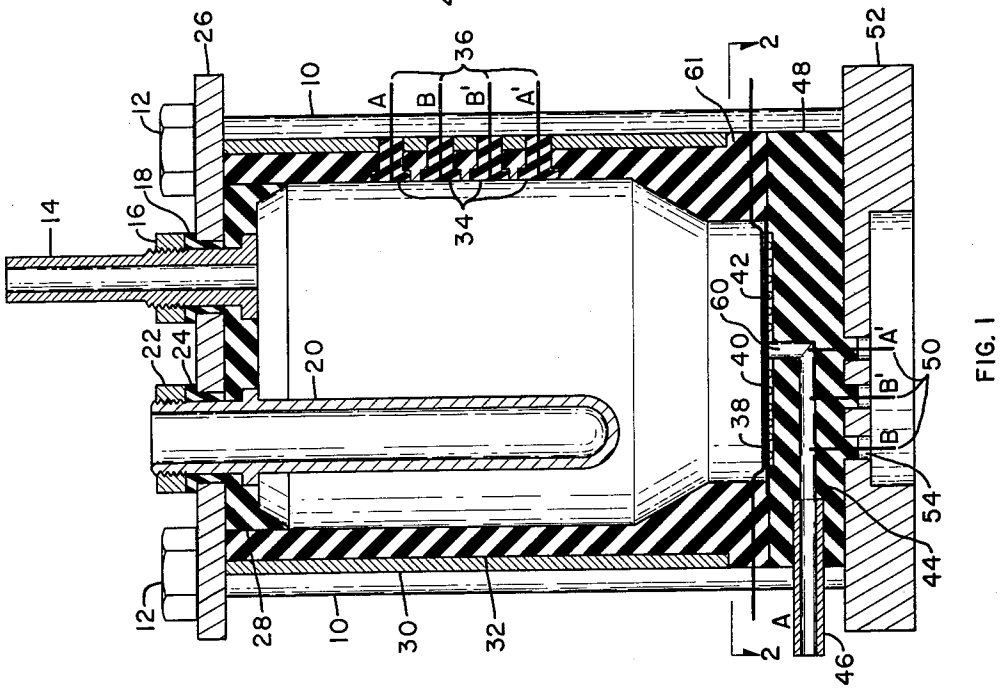


FIG. 1

Ralph D. Lynn Inventor

By W. V. Tolman Attorney

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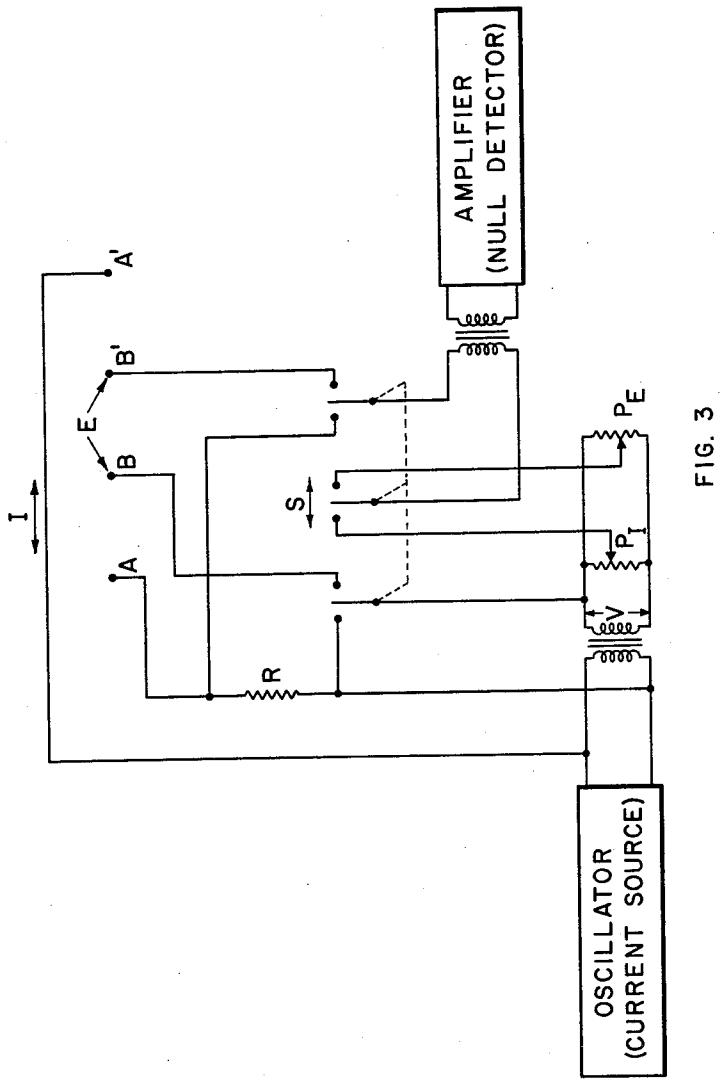


FIG. 3

Ralph D. Lynn Inventor

By W. V. Tolman Attorney

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CELL FOR DETERMINING DRILLING MUD RESISTIVITIES

Ralph D. Lynn, Tulsa, Okla., assignor to Jersey Production Research Company, a corporation of Delaware

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11 Claims. (Cl. 324—30)

The present invention is concerned with an improved method and apparatus for measuring the electrical resistivities of drilling muds. The present method and apparatus are unique in that it is possible to very quickly and accurately measure simultaneously the resistivity of the fluid drilling mud, the resistivity of the mud cake, and the resistivity of the mud filtrate. In essence, the cell comprises: a supporting bottom plate, a supporting cylindrical case, and a supporting top plate; a non-conducting bottom liner positioned on the bottom plate, a non-conducting cylindrical liner substantially positioned within the cylindrical case and a non-conducting top liner positioned below said top plate and uniquely positioned electrode terminals.

Provision is made in the top plate and top liner for a thermowell and port for the introduction of the fluid mud into the cell. Electrode terminals are provided in the cylindrical liner for the measurement of the electrical resistance of the fluid mud. The top of the bottom liner contains a labyrinth of drainage channels leading to a central port to within the bottom liner, where it is in communication with a substantially horizontal drain channel positioned within the bottom liner, which channel leads to without the bottom liner.

A filter means, such as a filter paper, is positioned on the top of the bottom liner. Thus in operation, the filter cake collects on top of the filter paper, the filtrate drains into the draining channels through the port and is withdrawn through the drain channel. Electrode terminals are provided in the drain channel for measuring the electrical resistance of the filtrate.

The non-conducting liner within the cylindrical case is characterized by a shoulder extending below the cylindrical case and which has substantially the same outside diameter as the cylindrical case. This shoulder seats on the filter positioned on the top of the lower liner. Electrode terminals comprising four closely spaced, horizontal wires pass completely through the shoulder of the liner. Thus in operation, the mud cake is formed about these wire electrode terminals which permits extremely accurate resistivity measurements of the cake.

It is well known in the production of and exploration for oil to drill well bore holes into the earth's substrata from the surface by various means, such as by the use of rotary equipment comprising rotary drill pipe, various types of drill bits, and the like. In these operations, it is the usual practice to circulate the drilling fluid downwardly within the drill pipe and upwardly in the annular area between the drill pipe and the bore hole wall. This drilling fluid or drilling mud serves a number of functions as for an example: to remove to the surface the drill cuttings, to secure a hydrostatic head if a pressure formation is encountered, and thus prevent blowouts, and also to form a mud cake on the bore hole wall, thus preventing undesirable entry of water and sand into the well being drilled.

During the well drilling operations, or on completion of the bore hole, it is also known to log the bore hole

by various methods. In essence, well logging denotes any operation in which some characteristic data of the formation being penetrated by the bore hole are recorded, generally in terms of depth. Based upon the information of the log, with respect to the various strata being penetrated, geologists, physicists, petroleum engineers and the like are able to determine with accuracy the character of the substrata and to some extent, the probability of oil reservoirs being present.

A very important technique of logging comprises electrical logging, wherein some form of electrical energy is used to determine the changes in the character of the strata penetrated or the type and nature of the strata about the bore hole. Electrical logging is essentially the recording of resistivity potentials generated, and the conductivities of the subsurface formations. When using electrical logging, down hole instruments are employed which measure in situ parameters and transmit these signals to the surface wherein they are suitably recorded and interpreted.

In order to interpret these electrical well logs quantitatively, it is necessary to know the resistivities of the fluid drilling mud being circulated, the mud cake which forms on the bore hole wall, and the mud filtrate in order to make the necessary corrections in the electrical signals.

In accordance with the present invention, a portion of the mud is passed through the cell and these three electrical resistance measurements accurately and efficiently secured. In general, the resistance values vary with temperature and thus with depths in the bore hole. These resistivities, as pointed out heretofore, also vary with mud composition. Furthermore, with the present invention, the relationships between the resistance of the drilling mud (R_m), the mud cake (R_{mc}), and the mud filtrate (R_{mf}) can readily be secured on different types of muds. This is particularly desirable with oil emulsion muds containing chemical additives and the like. In accordance with the present invention, these useful relationships by means of the technique and cell of the present invention are secured.

The complete apparatus comprises: a mud resistivity cell, a resistivity bridge, and a suitable hydraulic cylinder to pump the mud into the cell and to maintain the desired pressure on the mud. The mud resistivity cell serves as a mud press and provides a measurement of R_m, R_{mc}, and R_{mf}.

The cell comprises a metallic supporting bottom plate, a metallic supporting top plate, and a metallic supporting cylindrical case. The metal used may be any satisfactory material, but it is preferred, in accordance with the present invention, that it be aluminum. The cell also comprises a non-conducting bottom liner, a non-conducing cylindrical liner, and a non-conducting top liner. This liner may be of any type of non-conducting material, but it must be oil resistant, water resistant, immune to heat and also inert to the various known additives which comprise the mud composition. A preferred material comprises tetrafluoroethylene resin. This material is manufactured by the Du Pont Chemical Company, and is sold under the trade name of "Teflon." This material is a fluorocarbon, and is of a crystalline structure. It is manufactured by reacting calcium fluoride with sulfuric acid to give hydrogen fluoride which is reacted, in turn, with chloroform to give chlorodifluoromethane. This is converted by pyrolysis to gaseous tetrafluoroethylene monomer. The monomer is subsequently polymer-

ized under high pressure and temperature to give "Teflon." The polymer consists of long straight-chain molecules packed closely together. This structure and the strong chemical bond between carbon and fluorine in the molecule impart exceptional resistance to heat and chemicals.

The apparatus and process of the present invention may be readily understood by reference to the drawings outlining one embodiment of the same. FIGURE 1 is a vertical cross-sectional view of the cell; FIGURE 2 is a horizontal cross-sectional of the cell through 2—2; while FIGURE 3 is a diagrammatical illustration of the resistivity measuring circuit.

Referring specifically to FIGURE 1, the cell comprises a bottom supporting plate **52** having three holes **54** in the base thereof. A plurality of vertically extending shafts or rods **10** are positioned about the periphery of the supporting bottom plate. These shafts are threaded at the top end thereof. In the cell being described, three assembly shafts are employed. A Teflon bottom liner **48** seats on the top of supporting plate **52**. The top of bottom liner **48** contains a labyrinth of drainage channels leading to a central port **60** to within the bottom liner, wherein the port **60** is in communication with a substantially horizontal drain channel **44**, which channel leads to without the bottom liner. Three primary electrodes **50** extend through the base of the Teflon liner **48** and connect with drain **44**. These electrodes extend downwardly through the ports in supporting bottom plate **52**. Port **46** serves as the fourth primary electrode for measuring the resistivity of the filtrate passing through drain channel **44**.

A filter means, such as the filter paper **40**, is positioned above the channel drain area on the top of bottom liner **48**. A supporting cylindrical case **30** is positioned substantially completely about a non-conducting cylindrical liner **32**, which is Teflon. The cylindrical liner **32** extends below the cylindrical case and has a shoulder **61**, the outside diameter of which is substantially the same as the outside diameter of supporting cylindrical case **30**.

This shoulder **61** of liner **32** seats on the top of bottom liner **48** and filter **40**. Thus, it is possible for filtrate to pass through the filter **40** into port **60** and drain through **44**. The resistivity of this filtrate is readily determined by primary electrodes **50** and port **46**.

Four secondary electrodes **38**, which comprise four parallel wires, pass completely through the shoulder of the cylindrical liner from one side to the other. In the cell under description, the center-to-center spacing of these wires is about 0.05". Since the shoulder is seated on the filter, these secondary electrodes are just above the filter, and the filter cake will thus form about these secondary electrodes **38**, thus permitting an accurate electrical determination of the resistivity of the cake. These wire electrodes are from .015 to .050 inch above the filter.

Four tertiary electrodes **36** are positioned substantially half-way up the cylindrical case and extend from without case **30** to within cylindrical liner **32** by means of insulated bushings **34**. By means of these tertiary electrodes, it is possible to measure the resistivity of the fluid mud.

The diameter of the cylindrical case **30** is such as to permit it to be positioned within vertical shafts which extend upwardly from supporting plate **52**.

The top supporting plate **26** having holes in the periphery thereof and adapted to have assembly shafts **10** extend therethrough, has attached on its lower side an upper lining **28**. Plate **26** and liner **28** have extended therethrough thermowell **20**. A port **14** extends through plate **26** and liner **28**. Drilling mud is introduced into the cell through port **14**.

The shoulder **61** of liner **32** seats on the top of bottom **48** and filter **40**. Four tertiary electrodes **36** extend from without case **30** to within liner **32** by means of insulated bushings **34**. A nut **16** extends about inlet port **14**, while a nut **22** extends about thermometer well **20**.

An insulated bushing **24** is provided between nut **22** and the metal top plate **26**. An insulated bushing **18** is provided between nut **16** and top plate **26**. The insulated top liner **28** comprises Teflon.

FIGURE 2 is a horizontal cross-section taken through 2—2. Similar parts of FIGURES 1 and 2 are similarly numbered.

Referring specifically to FIGURE 3, the circuit, in essence, comprises: the resistivity bridge which may be divided, functionally, into three parts: namely, the signal generator, the null detector and the measuring circuit. The signal generator is a push-pull transistor oscillator. It provides about 5 milliamperes for the current electrodes. The frequency is about 900 cycles per second with a nearly sinusiodal waveform. The null detector is a four-stage transistor amplifier which provides a maximum voltage gain of about a million times. A microammeter reads the output of the amplifier. The output may also be heard on headphones. The null detector is used to indicate the balance on the measuring circuit. The measuring circuit contains two precision potentiometers: one measures the current between a pair of current electrodes; the other measures the potential between the corresponding pair of potential electrodes. The potential divided by the current equals the resistivity in ohm-meters times a constant. This constant has been determined for each set of electrodes by calculation and by experiments with known NaCl solutions.

In general, this circuit is as follows:

Rho=resistivity of material surrounding electrodes AA'BB'.

$$\text{Rho}=\frac{E}{I}\times \text{K}$$

K is a constant determined by geometrical arrangement with electrodes.

At null signal position of potentiometer P_I

$$V\times P_I=IR \text{ or } I=\frac{VP_I}{R}$$

and at null signal position of potentiometer P_E,

$$E=V\times P_E$$

Hence,

$$\text{Rho}=K\times\frac{E}{I}=\times\frac{R\times P_E}{P_I}$$

In essence, this circuit operates as follows:

The resistivity Rho is determined by measuring the current I, and the voltage E, separately. With switch S in the proper position, P_I is connected, through the amplifier input transformer, across the known resistor, R. The voltage across R due current I is of opposite polarity to the reference voltage V. Potentiometer P_I is adjusted for minimum signal as indicated by the Null Detector; then $V\times P_I$ represents the proportional part of V that is equal to $I\times R$. With switch S in the other position, similar adjustment of P_E is made and $V\times P_E$ is equal to the voltage E.

In operation, a sample is introduced into the cell by means of port **14** and a small amount allowed to pass through filter paper **40**, wherein the cake accumulates about electrodes **38**. The filtrate passes through port **44** and is withdrawn. Pressure is maintained on the mud through channel **14** and suitable means such as by a hydraulic pump. An electrical resistivity measurement of the drilling mud is determined by means of tertiary electrodes **36**, in conjunction with the resistivity circuit; a measurement of the resistivity of the filter cake is determined by means of secondary electrodes **38**, in conjunction with the resistivity circuit; the measurement of the resistivity of the filtrate is determined by primary electrodes **50**, in conjunction with the resistivity circuit.

In order to further illustrate the invention, the following examples are given:

Examples

A number of muds were tested with the cell and technique of the present invention with the following results:

	At 75° F.			At 150° F.		
	R_m	R_{mf}	R_{mc}	R_m	R_{mf}	R_{mc}
Sample 1	5.83	5.71	6.07	2.83	2.92	2.88
Sample 2	2.30	1.49	3.80	1.11	0.79	1.76
Sample 3	4.52	3.74	4.72	2.21	1.92	2.13
Sample 4	0.563	0.362	1.10	0.285	0.194	0.580

All resistivity values in ohm-meters.

A particularly desirable feature of the present invention is that the electrical resistance of the cake is determined without disturbing the cake, since the cake forms about the electrodes **38**.

Also, one great advantage of the cell of the present invention is that resistivity measurements can readily be made at elevated temperatures. It has been used over a temperature range of 75° F. to about 250° F. It also can be used over a wider range of 32° F. to about 400° F.

What is claimed is:

1. Improved apparatus for determining the electrical resistivity of a fluid drilling mud, the electrical resistivity of the mud cake, and the electrical resistivity of the filtrate which comprises: a metallic supporting bottom plate, a metallic supporting top plate, and a metallic cylindrical case positioned between said bottom plate and said top plate; a non-conducting bottom liner positioned on the top of said bottom plate, a non-conducting cylindrical liner substantially positioned within said cylindrical case, a non-conducting top liner positioned below said top plate, means for introducing a mud sample to within said cylindrical liner, tertiary electrode means extending from within said cylindrical liner to without said cylindrical liner and connected to an electrical resistivity measuring circuit; a filter positioned on the top of said bottom liner; closely spaced secondary electrode means above said filter means connected to an electrical resistivity measuring circuit whereby as said cake connects on said filter, it will form about and encase said secondary electrodes; a drain for removing filtrate, primary electrodes connected to said drain and to an electrical resistivity measuring circuit.

2. Apparatus as defined by claim 1, wherein said cylindrical liner extends below said cylindrical case and has a shoulder substantially the same diameter as the cylindrical case.

3. Apparatus as defined by claim 2, wherein said secondary electrodes comprise wires extending through the shoulder of said cylindrical liner.

4. Apparatus as defined by claim 1, wherein the top of said lower liner comprises a labyrinth of drainage channels draining to a central port to within said bottom liner and which communicates with said drain.

5. Apparatus as defined by claim 1, wherein said drain for removing said filtrate extends vertically downwardly within said bottom liner and then extends substantially horizontal within said bottom liner.

6. Apparatus for determining the electrical resistivity of a fluid mud, the electrical resistivity of the mud cake, and the electrical resistivity of the mud filtrate which comprises: a non-conducting bottom, a non-conducting cylinder positioned on said bottom; a non-conducting top positioned on said cylinder, means for introducing fluid mud into said cylinder; electrodes passing from within to without said cylinder and adapted to be connected to an electrical resistance measuring means; a filter positioned on top of said bottom; wires extending through said cylinder immediately above said filter and adapted to be connected to electrical resistance measuring means; a drain in said bottom and electrodes to said drain connected to an electrical resistance measuring means.

7. Apparatus as defined by claim 6, wherein said drain in said bottom passes vertically downwardly and then extends horizontally to without said bottom.

8. Apparatus as defined by claim 7, wherein the top of said bottom is characterized by having a labyrinth of channels on the top thereof.

9. In an apparatus for measuring the electrical resistivity of drilling mud, the drilling mud filter cake, and the drilling mud filtrate, including a cell having an electrically non-conducting inner surface and adapted to contain drilling mud, means to introduce drilling mud into said cell, and filter and drain means in the bottom of said cell adapted to permit mud filtrate to escape from said cell, the improvement which comprises: a first set of electrodes penetrating said cell above and removed from said filter; a second set of closely spaced electrodes penetrating said cell and positioned immediately above said filter whereby such electrodes are surrounded by mud cake upon filtration of drilling mud through said filter; and a third set of electrodes positioned within said drain; said first, said second, and said third sets of electrodes being adapted to be connected to electrical resistance measuring means.

10. An apparatus as defined in claim 9 in which said second set of electrodes comprises horizontal wires extending across said filter.

11. An apparatus as defined in claim 9 wherein each set of said electrodes comprises two current electrodes and two potential electrodes.

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